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SAAD, Sameh <http://orcid.org/0000-0002-9019-9636> and BAHADORI, Ramin

Published version

SAAD, Sameh and BAHADORI, Ramin (2020). Logistics capabilities measurement in the fractal supply network. International Journal of Logistics Systems and Management (IJLSM), 36 (2), 251-281.

Logistics capabilities measurement in the fractal supply network

Sameh M. Saad* and Ramin Bahadori

Department of Engineering and Mathematics, Sheffield Hallam University,
City Campus, Howard Street, Sheffield S1 1WB, UK
Email: S.Saad@shu.ac.uk
Email: b2047010@my.shu.ac.uk
*Corresponding author

Abstract: Measurement of logistics capabilities will enable firms to provide order winners by adding value for products and services during the different stage of supply chain to win the competition and enhance firm's performance and customer's satisfaction.

Therefore, the purpose of this research is to develop a Fuzzy-AHP multi-criteria decision-making model to measure logistics capabilities in the fractal supply network.

The key areas of measurement within a fractal supply network are identified and a hierarchical model is proposed with a set of generic measures. In addition, a questionnaire is developed for pair-wise comparison and to collect opinions from practitioners, researchers and managers to validate the proposed model. The relative importance of the measurement criteria is assessed using analytical hierarchy process (AHP) and Fuzzy-AHP. Hence, the validity of the model is confirmed with the results obtained.

Keywords: Fractal supply network, logistics capabilities measurement, supply chain, multi-criteria decision-making, Fuzzy-AHP.

Biographical notes: Professor Sameh M Saad, holds a BSc (Honours), MSc, PhD, PGCHE, CEng, MIET, MILT, FHEA, FCILT. He is the Professor of Enterprise Modelling and Management and also a Postgraduate Research Coordinator and MSc/MBA Course Leader in the Department of Engineering, Faculty of Arts, Computing, Engineering and Sciences, Sheffield Hallam University, UK. His research

interests and experience include fractal supply chain, modelling and simulation, technology road mapping, design and analysis of manufacturing systems, production planning and control, reconfigurable manufacturing systems and next generation of manufacturing systems including fractal and biological manufacturing systems. He has published over 150 articles in various national and international academic journals and conferences, including keynote, address a book and four patents.

Dr Ramin Bahadori holds a BSc, MSc, PhD, is Associate Lecturer in the Department of Engineering and Mathematics, Faculty of Arts, Computing, Engineering and Sciences, Sheffield Hallam University, UK. His research interest and experience include fractal supply chain, modelling and simulation, logistics capabilities, inventory optimisation, logistics cost optimisation, information system, green Vehicle Routing Problem, supply network integration, supply chain sustainability, communication and collaboration within supply network, technology road mapping, and multi-criteria decision-making fuzzy AHP.

1. Introduction

The fractal concept was entered into supply chain management from the early nineties by Warnecke, (1993); however, the overall number of research papers available on this topic is limited. Ryu and Jung (2003) defined concepts, architecture, and the major characteristics of the fractal manufacturing systems and modelled the basic fractal unit which consists of five functional modules including an observer, an analyser, a resolver, an organiser, and a reporter. Ryu et al. (2003) developed a framework for a company in terms of fractal concept and developed mathematical models for both analysers and resolvers as the main functional modules of each fractal. Saad and Lassila (2004) provided various fractal cell configuration methods for different system design objectives and constraints. Fan and Chen (2008) analysed the self-organisation attributes of the fractal supply chain, developed a self-organising dynamic model and applied them in the enterprise supply chain. He (2010) presented the mathematical model to evaluate the self-similarity characteristic in the fractal supply chain. Shin et al. (2009) proposed a method to facilitate the continuous and quick adaptation of a manufacturing system based on fractal organisation. Oh et al. (2010) developed a framework for collaborative supply chain management based on the fractal concept to analyse a trust model for production planning in the automotive industry. Saad and Aririguzo (2012) determined an optimal structural representation of the fractal manufacturing partnership (FMP), which facilitates the achievement of flexibility and swift responses to uncertainties in the manufacturing environment. Kleinikkink and Noori (2013) introduced and implemented a model based on the fractal concept to develop and increase manufacturing agility attributes and to quicken responses to uncertainty. Saad and Bahadori (2018) developed a new conceptual framework for an information fractal to optimise inventory including safety stock, cycle stock and prevent stock out at lowest logistics cost and further enhance integration within the network.

Logistics capabilities, due to its significant role in firm’s performance, have become a necessary aspect of supply chain management. Therefore, logistics capabilities have been receiving more attention from scholars during the recent decades. Morash et al. (1996) studied strategic logistics capabilities, including demand-oriented capabilities and supply-oriented capabilities, and determined the ranking of logistics capabilities in terms of importance to a firm’s success by utilizing the Stepwise Regression method while, Fawcett et al. (1997) represented a measure of the firm's logistics performance in five areas including flexibility, cost, quality, time, and innovation by using a regression analysis. They found the time-based capability to be the key factor. Stank and Lackey (1997) defined and measured logistics capabilities in the Mexican maquiladora firms based on a logistics competency model which was produced by Michigan State University. Zhao et al. (2001) tried to establish relationships among customer-oriented capabilities, information-oriented capabilities and firm performance using the statistical method. Liu and Ma (2005) analysed logistics capabilities, based on supply chain performance in terms of logistics operation capability and potential value-added logistics capability in a transportation enterprise, as a case study using Fuzzy mathematics and AHP methods. Liu and Ma (2006) developed a mathematical presentation in the supply chain to measure logistics capabilities in terms of logistics flux and circulation quantity. Li et al. (2008) explained logistics capabilities in the cluster supply chain based on the logistics service capability and the potential value-added logistics capability and tried to optimise the logistics capabilities using Fuzzy logic and AHP methods. Xu and Wang (2012) defined and analysed logistics capabilities among chain stores in China based on static ability and dynamic ability.

Gligor and Holcomb (2012) presented the systematic literature review as well as a conceptual model to show the relationship between logistics capabilities and supply chain agility.

1.1. Fractal supply network

A fractal supply network can be defined as a reconfigurable supply network which can present many different problem-solving methods in various situations (Fan and Chen, 2008).The fractal supply network attracts many in the industry because of its capabilities such as self-similarity, self-optimisation, self-organisation, goal orientation, and dynamics (Warnecke, 1993).

Self-similarity means each fractal unit is similar to another fractal unit whilst having their own structure (Attar and Kulkarni, 2014). Although, fractal units may have different conditions and internal structures in comparison to one another; they can have the same target in the system. Therefore, in the fractal supply network, fractals are self-similar if they can achieve goals in the system with different internal structures while inputs and outputs are the same (Ryu et al, 2013). Higher self-similarity in the supply network can increase the level of information sharing, operation coordination and the degree of integration among the fractal units and decrease the complexity of the system and ensure the supply network is understood and managed clearly (He, 2010).

Self-optimisation means each fractal unit is an independent unit with the ability to improve its own performance continuously. Fractals choose and use suitable methods to optimise operation and decision-making processes with the coordination of the whole system to achieve the goals (Attar and Kulkarni, 2014; He, 2010; Ryu et al, 2013).

Self-organisation (dynamic restructuring) refers to the support of the reconfiguration of network connections between fractals and the reorganisation of fractals in the system (Ryu and Jung, 2003). It means each fractal is free to make a decision about the organisation’s dimensions which is required for specific performance in regards to environmental parameters and the goals without external intervention (He, 2010; Leitão and Restivo, 1999). In fact, self- organisation is a kind of supply chain organisation which converts irregular conditions into regular conditions without outer monitoring and control to offer products and services to customers constantly (Fan and Chen, 2008).

Goal orientation enables the system goals to be achieved from the goals of individual fractals (Warnecke, 1993). Fractal units perform a goal-formation process to generate their own goals by coordinating processes with the participating fractals and modifying goals if necessary (Ryu and Jung, 2003).

Dynamics refer to the cooperation and coordination between self-organising fractals which are characterised by a highly individual dynamic and an ability to restructure their processes to meet and adapt to the dynamically changing environment (Ryu and Jung, 2003).

1.2. Logistics capabilities

Logistics capabilities require three steps including planning, implementing and controlling with a set of abilities and organisational processes as well as knowledge and skills that allow to add value to the products and services during the different stages of the supply chain, enabling order winners for the firms to win the competition and enhance the firm's performance and customer's satisfaction (Mentzer et al., 2004; Morash et al., 1996; Stank and Lackey, 1997; Zhao et al., 2001).

In accordance with the past literature, logistics capabilities can be categorised in a variety of ways; but based on analysis of previous literature and from authors' experience in this field, five main logistics capabilities are considered in this study: "*integration capability*", "*supply-oriented capability*", "*customer demand-oriented* *capability*", "*information exchange capability*" and "*Time management and logistics cost capability*".

1.2.1. Integration capability

Integration is necessary to achieve the unity of efforts to meet goals in the organisations and, consequently, have a positive relationship with the firm's performance (Stank et al., 2005). Integration, as a key logistics capability, is taken into consideration in much of the literature concerning logistics. Bowersox et al. (2003) discussed several elements of integration, including cross-functional unification, standardisation, simplification, structural adaptation, and compliance. Kahn and Mentzer (1996) defined inter-departmental integration and relates how such integration may impact logistics' performance including logistics' department performance success and overall company success. They indicated that the level of cross-functional integration is significantly related to new product development performance. Stank et al., (1999) studied the integration of marketing and logistics functions and claimed that a firm's performance and competitiveness are closely related to its logistics' integration. Williams et al. (1997) emphasised the importance of cross-functional coordination toward integration efficiency. Paulraj and Chen (2007) explored the connection between logistics integration and strategic buyer-supplier relationships regarding the firm's agility performance. Gimenez (2006) analysed both the internal and external integration processes within the Spanish food manufacturers and showed that companies must achieve the highest levels of integration in the logistics-production and logistics-marketing interface before starting any external integration. Themistocleous et al. (2004) conducted a case study to investigate the integration of supply chain management systems through enterprise application integration (EAI) technologies to achieve the physical integration of supply chain information systems. Caputo and

Mininno (1996) highlighted the importance of logistics integration into the marketing for better performance of online retailers.

1.2.2. Supply-oriented capability

Supply-oriented capability focuses on the internal customers' relationship and, also, the distribution network within the supply network to achieve both market value and the competitive advantage. Selective distribution coverage is one of the supply-oriented capability elements which enables a firm to target selective or exclusive distribution outlets effectively and provides the selected middlemen with higher profits (Mallen, 1971; Morash et al., 1996). Selective distribution can be distinguished in terms of the level of intensity of products distribution. It needs this careful examination to choose the number and types of intermediaries who are active in that particular market through which the product will be offered (Leigh and Gabel, 1992; Urbanska, 2007). Supplier selection, relationship, and involvement are the main aspects of supply-oriented capability helping firms to select and maintain high quality and reliable suppliers (Saad et al., 2012). As most firms spend a considerable amount of their revenues on purchasing; the supplier selection process has become one of the most important decision-making problems (Rostamzadeh, 2014). Selecting the right suppliers significantly reduces the purchasing costs and improves corporate competitiveness (Çebi and Bayraktar, 2003). Moreover, long-term supplier relationships lead to maximising the overall value of the manufacturer and customer satisfaction level, in turn, to a reduction in the product supply risk (Chan et al., 2008), in lead-time, in final product costs and in the potential increase of the product value (Wynstra et al., 2001). The next element of supply-oriented capability is reverse logistics which refers to all operations related to the re-use of products and materials in the supply network. Reverse logistics is a systematic process that manages the flow of products/parts from the point of consumption back to the point of manufacture for possible recycling, remanufacturing or disposal (Dowlatshahi, 2005). Effective reverse logistics lead to customer satisfaction improvement, decreases resource investment levels and reduces storage and distribution costs (Du and Evans, 2008). In addition, operating across different businesses and different regions enables firms to provide widespread and intensive distribution coverage to create a competitive advantage (Morash et al., 1996).

1.2.3. Customer demand-oriented capability

Customer demand-oriented capability is another key logistics capability which provides a competitive advantage for the firms by placing the focus on the product or the service differentiation and service enhancement to maximise the external customer satisfaction with unique, value-added activities (Mentzer et al., 2004; Morash et al., 1996; Stank et al., 2005). Customer service, as the output of the logistics system, is a vital area in logistics management that provides a differentiating element for achieving competitive advantages in the marketplace (Huiskonen and Pirttilä, 1998; Leuschner et al., 2013). Output improvement and the reconfiguration of products/services for the next lifecycle can be created in terms of quantity, time, place and quality which, consequently, have a positive effect on customer satisfaction and the firm's revenues (Ballou, 2006; Novack, 1987; Van der Meulen and Spijkerman, 1985). The sustainable, continued success of the firm comes from its ability to meet product/service needs of each major customer or customer segment. Thus, the use of appropriate customer segmentation strategies, in terms of logistics requirements, is an important aspect of customer demand-oriented capabilities (Bowersox et al., 1999; Zhao et al., 2001).

1.2.4. Information exchange capability

Information exchange capability is recognised as another logistic capability which has positive correlation with improving firms' performance and enabling firms to achieve a distinct, competitive differentiation in the marketplace by acquiring, analysing, storing, and distributing information both internally and externally through the supply network (Bowersox et al., 1999; Zhao et al., 2001). Computer-based information systems are playing a crucial role in the development of logistics as a management discipline (Gustin et al., 1995). Information systems development (Sandkuhl and Kirikova, 2011), the development of appropriate information technology, information sharing, and connectivity (Bowersox et al., 1999) are the major elements of the capabilities of information exchange.

1.2.5. Time management and logistics cost capability

Time management and logistics cost capability enable firms to manage both time and cost, effectively, to eliminate wasted capital and inventory, minimising logistics cost and increasing responsiveness within the supply network (Daugherty and Pittman, 1995; McGinnis and Kohn, 1993; Mentzer et al., 2000).

Logistics postponement and speculation strategies are key fundamentals of time management; logistics cost capability offers opportunities to achieve the delivery of products in a timely and cost-effective manner (Pagh and Cooper, 1998). Logistics postponement, as a combination of time and place postponement, involves delaying the forward movement of goods as long as possible and storing goods at central locations within the supply chain until customer orders are received (Stank et al., 2005; Wong et al., 2011). A successful example of logistics postponement is Ford's European Distribution Centre in which spare parts are distributed to dealers and garages within 24 to 48 hours (Hsuan Mikkola and Skjøtt-Larsen, 2004). In accordance with logistics speculation, finished products are shipped as inventory to the location closer to the customer (decentralized inventory), while the manufacturer waits for customer orders (Lin and Wu, 2013). Inventory cost, low total cost distribution, and responsiveness to customer demand fluctuations are other essentials of time management and logistics cost capability (Daugherty and Pittman, 1995; McGinnis and Kohn, 1990; Morash et al., 1996).

Figure 1 displays the conceptual structure of logistics capabilities in fractal supply network. The top level contains fractal supply network's members (e.g. Supplier, Supply Hub, Manufacturer, Distribution centre and Retailer). The middle level contains logistics capabilities' criteria which include Integration capability, Supply-oriented capability, Customer demand-oriented capability, Information exchange capability, and Time management and logistics cost capability. The bottom contains logistics capability elements related to each main criterion.

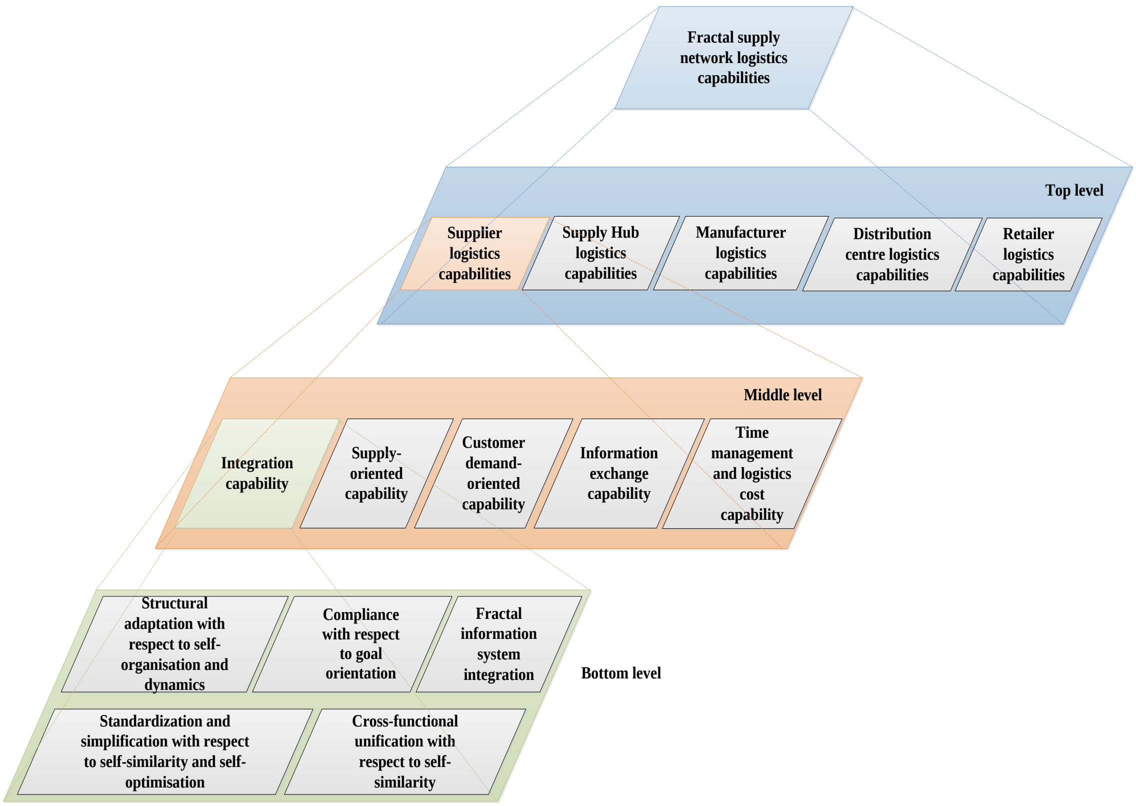

Figure 1: Conceptual structure of logistics capabilities in fractal supply network

The rest of the paper is organised as follows. In the next section, the methodologies used for this study and the steps to follow are outlined. In the third and fourth sections, the work carried out using the AHP method and Fuzzy-AHP for evaluating the priority of the main criteria, sub-criteria and lower sub-criteria in fractal supply network are explained respectively. Results obtained from the comparison between classical AHP and fuzzy AHP is shown in the fifth section. In the sixth section, a sensitivity analysis is presented to further understand how the changes in priority of the criteria affect the overall results. Then the paper ends with overall conclusions and future work.

2. Methodology

In this study, two methodologies; analytical hierarchy process (AHP) and Fuzzy-AHP are used to assess relative importance of the measurement criteria.

2.1. Analytic hierarchy process (AHP)

The analytic hierarchy process (AHP) is one of the most widely-used methods in the Multiple Attribute Decision-Making (MADM) problem which was proposed in 1980 by Thomas L. Saaty. Scope and a variety of used AHP in different areas such as evaluation, cost-benefit analysis and allocation, planning and development, priority and ranking, decision making, forecasting and strategic planning, which have been very extensive (Vaidya and Kumar, 2006). This technique formulated the problem in a hierarchical format, combining both quantitative and qualitative criteria at the same time, involving different alternatives in decision-making, and providing a sensitivity analysis on criteria and sub-criteria. In addition, AHP is built based on a pairwise comparison which facilitates both the judgments and calculations. Moreover, the technique presents the consistency and inconsistency of the decision which are the distinctive advantages of this technique (Saaty and Sodenkamp, 2008). Analytical Hierarchy Process steps can be explained as follows briefly:

- Step 1: Constructing the hierarchical model. AHP is a graphical representation of a real, complex problem where the overall goal is the top of the hierarchical model, followed by main-criteria and sub-criteria in the subsequent levels and, finally, at the lowest level possible, alternatives are placed. This situation provides a general and standardised framework that, for all problems regardless of their type, will be identical. The criteria for the performance evaluation of each dimension should be mutually independent (Saaty, 1988).
- Step 2: A pairwise comparison of criteria and alternatives for development of judgment matrices. This step includes the pair-wise comparison of elements which are inserted in each level of the hierarchical model with respect to the main goal or elements in the higher level performed by decision makers to find the comparative weights among the attributes of the decided element and are inserted in the matrix, namely the "pair-wise comparison matrix". The scale for these pair-wise comparisons are introduced based on a standard evaluation scheme as shown in table 1, which enables the decision-makers to express preference or importance between each pair of elements with respect to the main goal or higher criterion by incorporating their experience and knowledge (Saaty, 1988; Saaty and Vargas, 1994).

Table 1: Scale of Relative Importance

Intensity of importance	Definition	Explanation
1	Equally important	Two activities contribute equally to the objective
3	Moderate Importance	Experience and judgment slightly favour one activity over another
5	Strong Importance	Experience and judgment strongly favour one activity over another
7	Very strong Importance	An activity is strongly favoured and its dominance demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed

- Step 3: Derivation of priorities: After a pair-wise comparison is completed, the next step is to calculate the local priorities from the judgment matrices. The Eigen value Method (EVM), the Logarithmic Least Squares Method (LLSM), the Weighted Least Squares Method (WLSM), the Goal Programming Method (GPM) and the Fuzzy Programming Method (FPM) are the main calculation methods summarised by (Mikhailov, 2000).
- Step 4: Synthesizing the results: After obtaining the local priorities for the criteria, sub-criteria and the possible alternatives through pairwise comparisons, the final priorities of the elements are located in the kth level of the hierarchical model, with respect to the main goal, will be calculated.
- In addition to the combination of hierarchy levels and considering the multiple elements, AHP has distinct advantages in calculating the consistency ratio to determine the consistency of the comparisons. This mechanism shows the extent to which the judgements and priorities can be trusted. In general, a consistency ratio with equal or less than ten percent can be taken as sufficiently consistent.

(Saaty, 1980) suggested using the consistency index to measure the degree of consistency using the following equation:

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{1}$$

Where:

- CI= Consistency index
- λmax= Maximal eigenvalue
- n= Dimension of square matrix

Then the consistency ratio is generated by the comparison of the value of consistency index and the random indices:

$$CR = \frac{CI}{RI} \tag{2}$$

Where:

- *CR*= Consistency Ratio
- *RI*= Random Consistency Index

In this work, the consistency is investigated by the use of Expert Choice Software.

2. Fuzzy-AHP methodology

The AHP method bears comparison to human thinking. AHP breaks down a complex decision-making process into simple comparisons. However, it does not consider cognitive factors of human judgement (Sarfaraz et al., 2012). Uncertainty in the preference judgements increases the uncertainty in the prioritisation of alternatives and, to the same ratio; it makes it difficult to determine the logical consistency of the priorities (Leung and Cao, 2000). Therefore, to overcome these problems Fuzzy-AHP is provided. There are several methods proposed in the literature for using Fuzzy-AHP (Buckley, 1985; Chang, 1996; Van Laarhoven and Pedrycz, 1983). In this research, the extent analysis method (Chang, 1996), due to its popularity, has been used based on triangular fuzzy numbers (TFNs) to measure logistics capabilities in the fractal supply network.

In summary, the purpose of Fuzzy-AHP is to deal with a complex decision-making problem by decomposition of these problems into a hierarchy with the main goal (criterion) at the top, and, then, the criteria and sub-criteria and possible alternatives at the bottom level (Saad et al., 2016). All the elements are compared, in pairs, to assess its relative importance in the level as well as the level above; the method computes eigenvectors until the composite final vector is obtained. The final vector of weights (global weight) shows the relative importance of each alternative towards the main goal (Sharma and Yu, 2014).

Fuzzy AHP is a range of values to deal with uncertainties for decision makers (see Table 2).

Table 2: Triangular Fuzzy Conversion Scale (Prakash, 2003)

Importance Intensity	**Triangular Fuzzy scale**	**Importance Intensity**	**Triangular Fuzzy Scale**
1	(1,1,1)	1/1	(1/1, 1/1, 1/1)
2	(1,2,4)	1/2	(1/4, 1/2, 1/1)
3	(1,3,5)	1/3	(1/5, 1/3, 1/1)
5	(3,5,7)	1/5	(1/7, 1/5, 1/3)
7	(5,7,9)	1/7	(1/9, 1/7, 1/5)
9	(7,9,11)	1/9	(1/11, 1/9, 1/7)

Consider a triangular fuzzy comparison matrix expressed by:

$$\tilde{A} = (\tilde{a}ij)_{n\times n} \begin{bmatrix} (1,1,1) & (l_{12}, m_{12}, u_{12}) & \cdots & (l_{1n}, m_{1n}, u_{1n}) \\ (l_{21}, m_{21}, u_{21}) & (1,1,1) & \cdots & (l_{2n}, m_{2n}, u_{21}) \\ \vdots & \vdots & \ddots & \vdots \\ (l_{n1}, m_{n1}, u_{n1}) & (l_{n2}, m_{n2}, u_{n2}) & \cdots & (1,1,1) \end{bmatrix}$$

Where

$$\tilde{a}_{ij} = \begin{cases} 1 & i = j \\ (l_{ij}, m_{ij}, u_{ij}) \ or \ (\frac{1}{u_{ij}}, \frac{1}{m_i}, \frac{1}{l_{ij}}) & i \neq j \end{cases}$$

Where:

- *l*= The lower bound of the triangular fuzzy set
- *m*= The mean bound of the triangular fuzzy set
- *u*= The upper bound of the triangular fuzzy set
- *i*= The row number
- *j*= The column number

In this paper, a priority vector is determined by the aforementioned triangular fuzzy comparison matrix, the extent analysis method is used, and its steps are described briefly as follows:

Firstly, determine the synthetic extent value, which is a triangular fuzzy number, for each row of fuzzy pairwise comparison matrix:

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} \tag{3}$$

Where:

- S_i= The synthetic extent value
- M_{gi}^{j}= The triangular fuzzy numbers of pair wise comparison matrix

Where

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j , \sum_{j=1}^{m} m_j , \sum_{j=1}^{m} u_j \right) \tag{4}$$

And

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{i=1}^{n} l_i , \sum_{i=1}^{n} m_i , \sum_{i=1}^{n} u_i \right) \tag{5}$$

And

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} = \frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i} \tag{6}$$

Secondly, determine the degree of possibility of triangular fuzzy numbers (S_i). In general, if M_1= (l_1, m_1, u_1) and M_2= (l_2, m_2, u_2) be the two triangular fuzzy numbers, in accordance with figure 2 the degree of possibility of M_1 toward the M_2 can be defined as follows:

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = u_{M_2}(d)$$

$$= \begin{cases} 1 & if\ m_2 \geq m_1 \\ 0 & if\ l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & otherwise \end{cases} \tag{7}$$

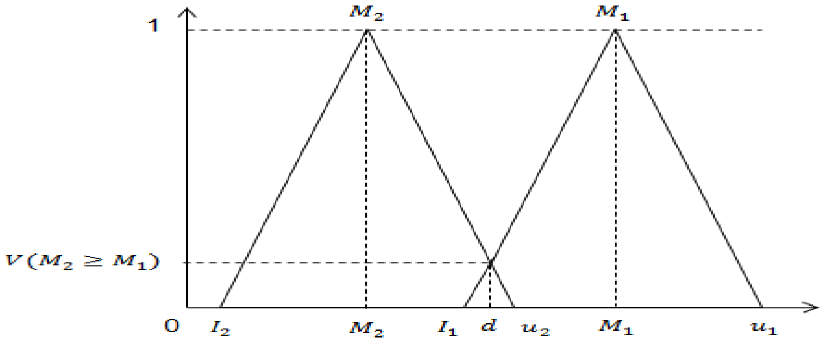

Figure 2: The Intersection between TFNs (Chang, 1996)

Moreover, the degree of possibility of a convex fuzzy number to be greater than *k* convex fuzzy numbers can be defined as follows:

$$V(M \geq M_1, M_2, \ldots, M_K) = V[(M \geq M_1)\, and (M \geq M_2)\, and \ldots and\, (M \geq M_k)]$$
$$= Min\, V\,(M \geq M_i), i = 1, 2, 3, \ldots, k \qquad (8)$$

Thirdly, determine the weights of criteria, sub-criteria and possible alternatives:

$$d'(A_i) = Min\, V\,(S_i \geq S_k) \quad k = 1, 2, \ldots, n\ ,\ \ k \neq i \qquad (9)$$

Fourthly, determine the weight vector:

$$W' = \left(d'(A_1), d'(A_1), \ldots, d'(A_n)\right)^T \qquad (10)$$

Finally, via normalization, the normalised weight vectors:

$$W = \left(d'(A_1), d'(A_1), \ldots, d'(A_n)\right)^T, W \neq \text{fuzzy number} \qquad (11)$$

3. Application of AHP

It is clear that from figure 1 that the AHP is the most appropriate method to represent the hierarchical structure of the logistics capabilities in the fractal supply network. Therefore, in this section, the usage of AHP method for evaluating importance priority of main criteria, sub-criteria and lower sub criteria in fractal supply network is explained.

3.1. Structuring the hierarchy

The first step of using AHP to model a decision problem is to structure the hierarchy.

With respect to the proposed conceptual structure, which is presented in the previous section, the hierarchical model is developed as shown in figure 3.

The main goal of this research is to measure logistics capabilities in the fractal supply network and is placed at the top of the hierarchical model. From which, five criteria are descended in the second level (e.g. Supplier, supply hub, manufacture, distribution centre and retailer). This is followed by five major logistics capabilities factors (e.g. Integration, supply-oriented, customer demand-oriented, information exchange, and time management and logistics cost) located in the third level as sub-criteria under each criterion and logistics capabilities elements (e.g. Cross-functional unification with respect to self-similarity, etc.) as lower sub-criteria located under the relevant logistics capabilities factor in the fourth level.

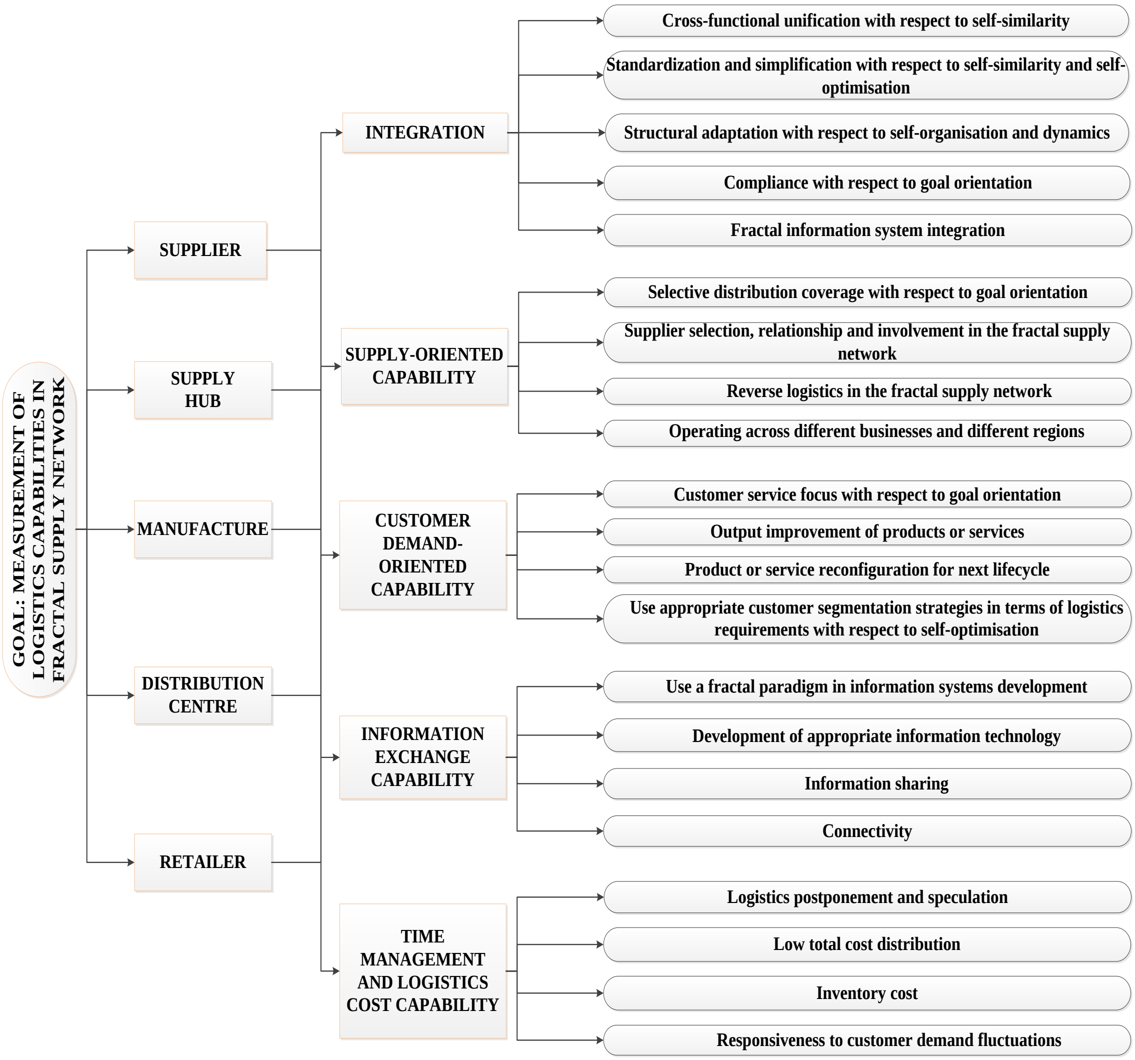

Figure 3: The proposed multi criteria decision making model

3.2. Performing pairwise comparisons

Pairwise comparisons were performed systematically to include all the combinations of main criteria, sub-criteria and lower sub criteria relationships. For that, a questionnaire was designed for data collection purposes from academics and industrialists who were recognised and selected carefully by research team as the professional experts in this particular research area. The questionnaire was developed based on the criteria and levels in the AHP model. Experts who have been asked to make pair-wise comparisons between the two factors/criterion at a time, decide which factor is more important and then specify the degree of importance on a scale between one (equal importance) and nine (absolutely more important) of the most important factor/criteria. In total, 50 people responded to the questionnaire survey and, of them, 18 were academics and 32 were industrialists. All the responders agreed about the proposed model and showed positive responses towards logistics capability in the fractal supply network and its necessity.

The data collected from the questionnaire survey has been converted into a geometric mean to measure the pair wise comparison of each criterion. Among the responses from the feedback, all the participants agreed with the model. As different participants each have different opinions about each criterion, a geometrical mean method is used to convert the different judgements into one figure for each criterion and sub-criteria.

The following formula is used to calculate the geometric mean.The following formula is used to calculate the geometric mean.

$$\text{Geometric mean} = [(x_1)(x_2)(x_3) \ldots (x_n)]^{1/n} \quad (12)$$

Where

- x= individual weight of each judgment
- n = sample size (number of judgment)

3.3. Derivation of priorities

In this study, Expert Choice Software was used to drive the local priorities of the criteria, sub-criteria and lower sub-criteria. The judgement of the five main criteria located in level two is entered. The conclusion was that *Manufacturer* was the most important criterion (manufacturer = 0.332) followed by *Supplier* (0.308), *Supply hub* (0.135), *Distribution Centre* (0.127) and *Retailer* with the least ranking (0.098). Moreover, the inconsistency rate of the main criteria matrix was 4%, less than the acceptable minimum rate of 10%. Therefore, the inconsistency level is acceptable, and the results show a high level of accuracy (see Figure 4). After comparing the major criteria, the sub-criteria and the lower sub-criteria were evaluated. (See appendix1).

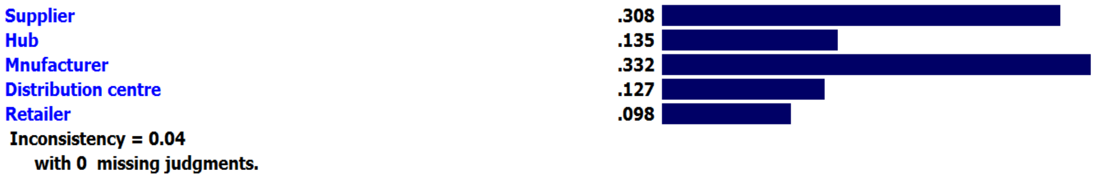

Figure 4: Main criteria prioritization with respect to the main goal "A Fractal supply network logistics capability measurement" and inconsistency measurement

3.4. Synthesizing the results (AHP)

After deriving the local priorities for the criteria, sub-criteria and lower sub criteria through pairwise comparisons, the synthesis analysis has been completed to understand the global priorities of lower sub criteria towards the main goal (see equation 13).

$$G_{SG} = \sum_{k=1}^{n} \sum_{i=1}^{m} W_k \times W_i \times W_{ij} \tag{13}$$

Where:

- G_{SG}= Global priorities of the lower sub-criteria with respect to the main goal
- W_k = local weight of main criteria k.
- W_i = local weight of sub-criteria i.
- W_{ij} = local weight of the lower sub-criteria with respect to the sub-criteria i.

As shown in figure 5, *Responsiveness to customer demand fluctuations* received the highest ranking (10.7 %), followed by *Customer service focus with respect to goal orientation* (9.8%), *Supplier selection, relationship and involvement in the fractal supply network* (7.9%) and both *Reverse logistics in the fractal supply network* and *Operating across different businesses and different regions* (1.9 %) were the lowest ranking with respect to the 'Main Goal'.

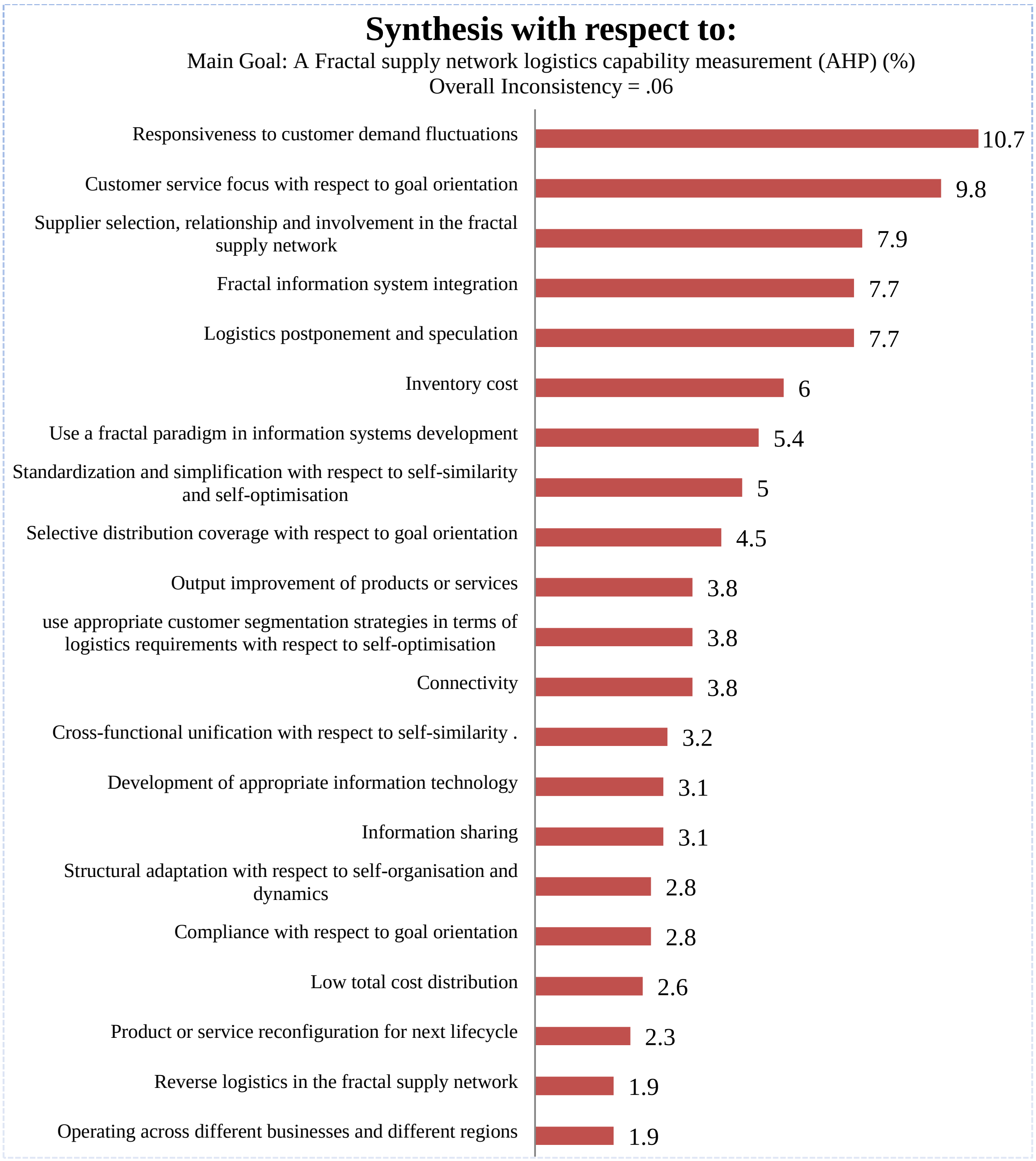

Figure 5: Synthesis with respect to main goal: A Fractal supply network logistics capability measurement (AHP) (%)

4. Application of Fuzzy-AHP

4.1. The fuzzy evaluation matrix with respect to "Main Goal"

In the first step, the AHP matrix is converted into fuzzy matrix using the fuzzy conversion scale. Table 3 presents the converted matrix using TFN for the main criteria "Supplier, Supply hub, Manufacturer, Distribution centre and Retailer" with respect to the main goal which is creating "A Fractal supply network logistics capability measurement".

Table 3: Fuzzy comparison matrix with respect to the 'Main Goal'

	Supplier	Supply Hub	Manufacturer	Distribution centre	Retailer
Supplier	(1,1,1)	(1,3,5)	(1,1,1)	(1,2,4)	(1,3,5)
Supply hub	(1/5,1/3,1/1)	(1,1,1)	(1/5,1/3,1/1)	(1,2,4)	(1,1,1)
Manufacture	(1,1,1)	(1,3,5)	(1,1,1)	(1,3,5)	(1,3,5)
Distribution centre	(1/4,1/2,1/1)	(1/4,1/2,1/1)	(1/5,1/3,1/1)	(1,1,1)	(1,2,4)
Retailer	(1/5,1/3,1/1)	(1,1,1)	(1/5,1/3,1/1)	(1/4,1/2,1/1)	(1,1,1)

Next, in accordance with equation (3), the fuzzy synthetic extent values, with respect to the Main Goal, are determined as follows:

$S_{Supplier}$= (5, 10, 16) ⊗ (0.0185, 0.0302, 0.0533) = (0.0925, 0.302, 0.8528)

$S_{Supply\ hub}$= (3.4, 4.66, 8) ⊗ (0.0185, 0.0302, 0.0533) = (0.063, 0.14, 0.426)

$S_{Manufacture}$ = (5, 11, 17) ⊗ (0.0185, 0.0302, 0.0533) = (0.092, 0.332, 0.906)

$S_{Distribution\ center}$ = (2.7, 4.33, 8) ⊗ (0.0185, 0.0302, 0.0533) = (0.05, 0.130, 0.426)

$S_{Retailer}$= (2.65, 3.166, 5) ⊗ (0.0185, 0.0302, 0.0533) = (0.049, 0.095, 0.266)

Then, degree of possibility of these synthetic values is computed [follow equation (7)]:

$V(S_{Supplier} \geq S_{Supply\ hub}) = 1$, $V(S_{Supplier} \geq S_{Manufacturer}) = 0.962$, $V(S_{Supplier} \geq S_{Distribution\ centre}) = 1$, $V(S_{Supplier} \geq S_{Retailer}) = 1$

$V(S_{Supply\ hub} \geq S_{Supplier}) = 0.673$, $V(S_{Supply\ hub} \geq S_{Manufacturer}) = 0.635$, $V(S_{Supply\ hub} \geq S_{Distribution\ centre}) = 1$, $V(S_{Supply\ hub} \geq S_{Retailer}) = 1$

$V(S_{Manufacturer} \geq S_{Supplier}) = 1$, $V(S_{Manufacturer} \geq S_{Supply\ hub}) = 1$, $V(S_{Manufacturer} \geq S_{Distribution\ centre}) = 1$, $V(S_{Manufacturer} \geq S_{Retailer}) = 1$

$V(S_{Distribution\ centre} \geq S_{Supplier}) = 0.66$, $V(S_{Distribution\ centre} \geq S_{Supply\ hub}) = 0.973$, $V(S_{Distribution\ centre} \geq S_{Manufacturer}) = 0.623$, $V(S_{Distribution\ centre} \geq S_{Retailer}) = 1$

$V(S_{Retailer} \geq S_{Supplier}) = 0.457$, $V(S_{Retailer} \geq S_{Supply\ hub}) = 0.819$, $V(S_{Retailer} \geq S_{Manufacturer}) = 0.423$, $V(S_{Retailer} \geq S_{Distribution\ centre}) = 0.860$

In the next step, weights of each main criterion are determined using the equation (9):

$d'(Supplier) = min\ (1, 0.962, 1, 1) = 0.962$

$d'(Supply\ hub) = min\ (0.673, 0.635, 1, 1) = 0.635$

$d'(Manufacturer) = min\ (1, 1, 1, 1) = 1$

$d'(Distribution\ centre) = min\ (0.66, 0.973, 0.623, 1) = 0.623$

$d'(Retailer) = min\ (0.457, 0.819, 0.423, 0.860) = 0.423$

And the weight vector is obtained using the minimum of the degrees of possibility which are found as above [follow equation (10)]:

$W' = (0.962, 0.635, 1, 0.623, 0.423)^T$

Finally, equation (11) is used to normalize the priority weights of the main criteria with respect to the Main Goal:

$$W_{Main\ Criteria} = (\ 0.264, 0.174, 0.274, 0.171, 0.116\ )^T$$

According to the results, Manufacture was the most important criteria (0.274), followed by Supplier (0.264), Supply hub and Distribution Centre were close behind (0.174 & 0.171) respectively, and retailer was the lowest important main criteria (0.116) with respect to the 'Main Goal'.

The abovementioned steps were applied to the rest of the matrixes which represents the pairwise comparison of sub-criteria and lower sub-criteria and the local priorities were obtained. (See appendix 2).

4.2. Synthesizing the results (Fuzzy-AHP)

After deriving the local priorities for the criteria, sub-criteria and lower sub criteria through pairwise comparisons, the synthesis analysis has been done to understand the global priorities of the lower sub criteria towards the main goal and each main criterion using equation (13).

Customer service focus, with respect to goal orientation, received the highest ranking (8.3%), followed by *Responsiveness to customer demand fluctuations* (8%), *Use of a fractal paradigm in information systems development* (7.6%) and *Structural adaptation, with respect to self-organisation and dynamics,* was the lowest ranked (2.4%) with respect to the 'main goal'.

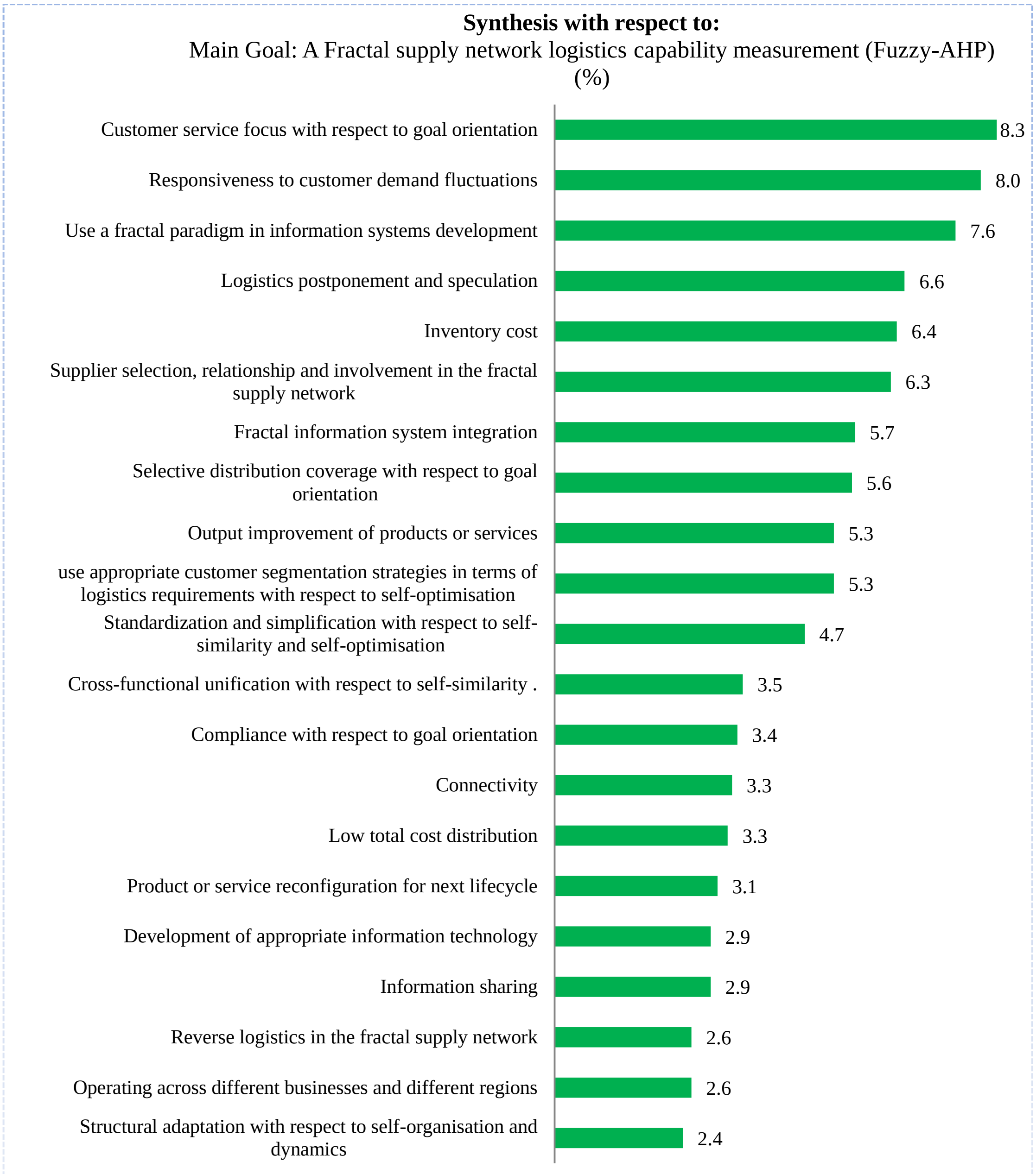

Figure 6: Synthesis with respect to main goal: A Fractal supply network logistics capability measurement (Fuzzy- AHP) (%)

5. Comparison between classical AHP and Fuzzy AHP results

Table 4 shows the comparison between local weights derived within each methodology. There is a slight difference between classical AHP prioritisation ratio and Fuzzy AHP ratio. As Fuzzy AHP considers a set of values (TFN) rather than a single value, the prioritisation will be more certain. It is noticeable that, as shown in figures 5 and 6, the global Fuzzy AHP weights, with respect to the main goal, also shows that there is a slight difference in the importance of elements in each criterion with respect to the classical AHP.

Table 4: Comparison between classical AHP and Fuzzy AHP results (%)

Main criteria	Sub-criteria	Fuzzy-AHP	Classical AHP
Supplier	Integration capability	28.2	37.9
	Supply-oriented capability	18	14.2
	Customer demand-oriented capability	24	22
	Information exchange capability	18.1	15.4
	Time management and logistics cost capability	11.7	10.6
Supply hub	Integration capability	26.1	25.5
	Supply-oriented capability	30.6	42.3
	Customer demand-oriented capability	21	14.4
	Information exchange capability	4.8	5.5
	Time management and logistics cost capability	17.5	12.3
Manufacturer	Integration capability	14.1	12
	Supply-oriented capability	4.4	5.2
	Customer demand-oriented capability	21.9	17.4
	Information exchange capability	18.8	14.8
	Time management and logistics cost capability	40.8	50.6
Distribution centre	Integration capability	8.4	7.1
	Supply-oriented capability	15.6	11.8
	Customer demand-oriented capability	15.6	11.8
	Information exchange capability	30.2	34.6
	Time management and logistics cost capability	30.2	34.6
Retailer	Integration capability	21.6	16
	Supply-oriented capability	26.9	29
	Customer demand-oriented capability	28.1	39.3
	Information exchange capability	7.4	6.2
	Time management and logistics cost capability	16	9.5

6. Sensitivity analysis

In this work, the dynamic sensitivity of Expert Choice was applied to dynamically change the priorities of the main criteria to determine how these changes affect the priorities on the lower sub-criteria. Therefore, the impact of changing the priority of five main criteria ‘Supplier, Supply Hub, Manufacturer, Distribution centre and Retailer’ on overall results has been investigated (See appendix 3).

- First scenario: when the priority of “Supplier” was dropped to the fourth priority (from 31.2% to 15.2%) the highest and the lowest priority of the final ranking of the lower sub-criteria were preserved whilst the Logistics postponement and speculation and Inventory cost were raised to the fourth and fifth priority of the final ranking with 8.8% and 6.9% respectively.
- Second scenario: when the priority of ‘Supply hub’ was increased to the highest priority (from 13% to 25%) Supplier selection, relationship and involvement in the fractal supply network was raised to the most important lower sub-criteria with 10.3% and Products or services reconfiguration for next lifecycle was ranked the lowest with respect to the ‘main goal’.
- Third scenario: when the priority of ‘Manufacturer’ was dropped to the lowest priority (from 33.8% to 12.3%) Customer service focus, with respect to goal orientation, was raised to the highest ranking with 10.2%, followed by Supplier selection, relationship and involvement in the fractal supply network with 9.6%, Fractal information system integration with 8.8 % and Low total distribution cost was the lowest ranking with 1.9%
- Fourth scenario: when the priority of ‘Distribution Centre’ was raised to the highest priority (from 12.2% to 28.5%). The highest and the lowest priority of the final ranking of lower sub-criteria were preserved while the Logistics postponement and speculation received the third priority with 8.1% instead of Supplier selection, relationship and involvement in the fractal supply network.
- Fifth scenario: when ‘Retailer’ received the highest priority (from 10.4% to 27.8%), Customer service focus with respect to goal orientation was raised to

the highest priority with 11.7% instead of Responsiveness to customer demand fluctuations and both Reverse logistics in the fractal supply network and Operating across different businesses and different regions with 2.2% were still the lowest ranked.

7. Conclusions

Measuring logistics capability is one of the challenging issues in today's competitive business scenario. An efficient and effective measurement can lead to improvement in the process and, thus, competitiveness can be achieved. Unlike previous research, this paper considered the logistics capabilities from the perspective of a fractal supply network and the majority of logistics categories which are rarely carried out within previous literature.

In this study, the criteria for measuring logistics capabilities in the fractal supply network have been decided based on the previous literature, fractal capabilities and expert's judgements in this field. Considering the imprecise judgement faced by decision makers from classical AHP methodology, a fuzzy AHP methodology has also been used in this study to attain a clearer, more precise, priority from each level of judgement for measurement depending on their criticality. Moreover, a sensitivity analysis has been applied in this work to understand how the changes in priority of one criterion affect another.

Thus, this research paper provides a systematic method through which practitioners should be able to decide upon the different logistics capabilities criteria, sub-criteria and key elements to test and assess and improve an enterprise's logistics capabilities.

During the course of this research, it became apparent that research in this area still needs more attention. Therefore, many of the new approaches are still fairly abstract concepts and there are several areas for future work within the scope of this research.

Hence, and as a road map for future research in this area, it would be beneficial to identify to what extent the priorities of logistics capabilities are similar for the fractal supply network members (e.g. Supplier, Supply hub, Manufacture, Distribution centre and Retailer).

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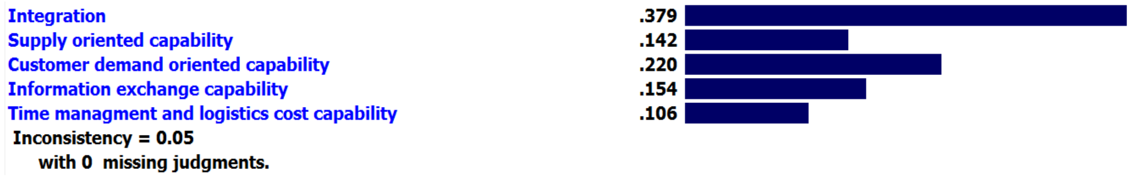
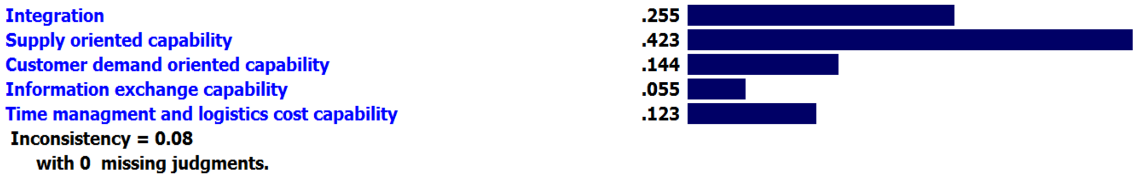
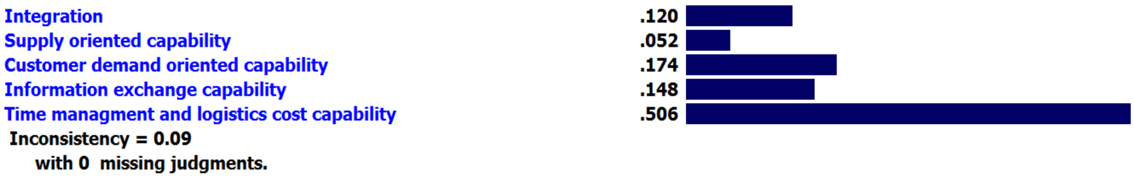
Appendix 1: Derivation of local priorities of the sub-criteria and Lower sub-criteria (Expert Choice software application)



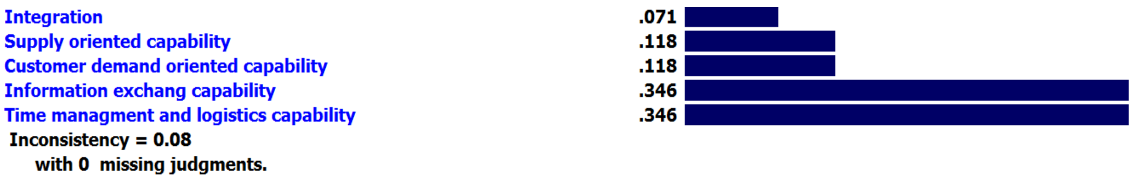
Sub-criteria prioritization with respect to the "Supplier" and inconsistency measurement



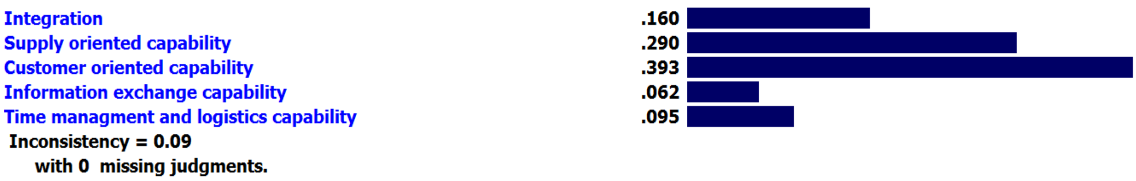
Sub-criteria prioritization with respect to the "Supply hub" and inconsistency measurement



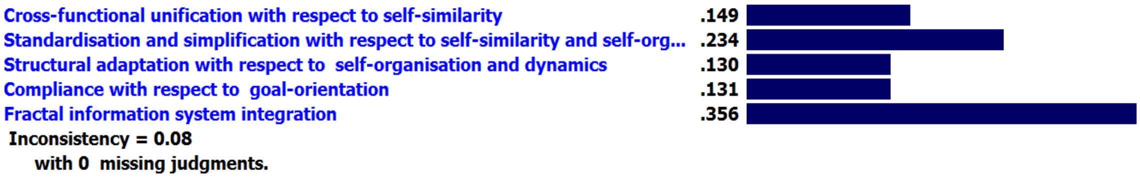
Sub-criteria prioritization with respect to the "Manufacturer" and inconsistency measurement



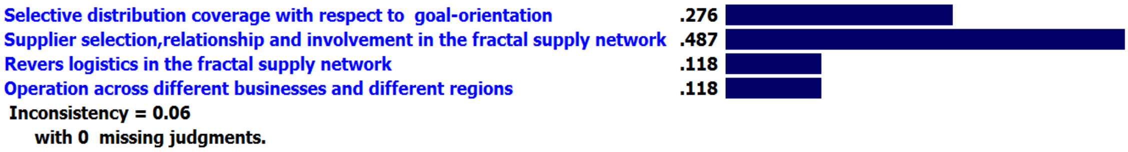
Sub-criteria prioritization with respect to the "Distribution centre" and inconsistency measurement



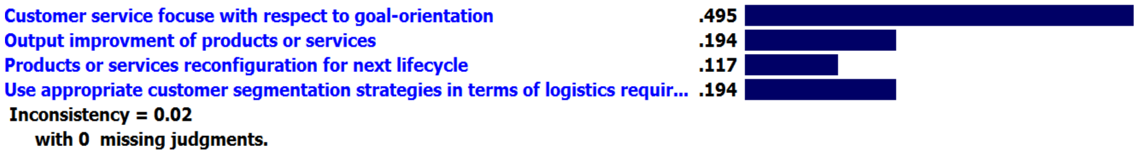
Sub-criteria prioritization with respect to the "Retailer" and inconsistency measurement



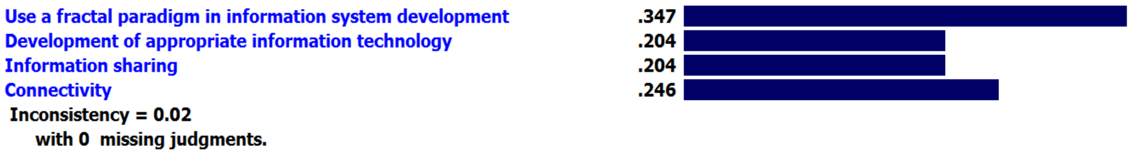
Lower sub-criteria prioritization with respect to the "Integration" and inconsistency measurement



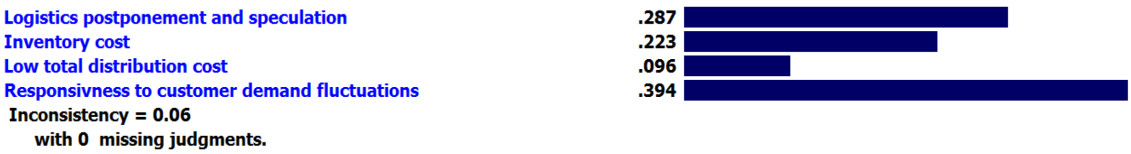
Lower sub-criteria prioritization with respect to the "Supply-oriented capability" and inconsistency measurement



Lower sub-criteria prioritization with respect to the "Customer demand-oriented capability" and inconsistency measurement



Lower sub-criteria prioritization with respect to the "Information exchange capability" and inconsistency measurement

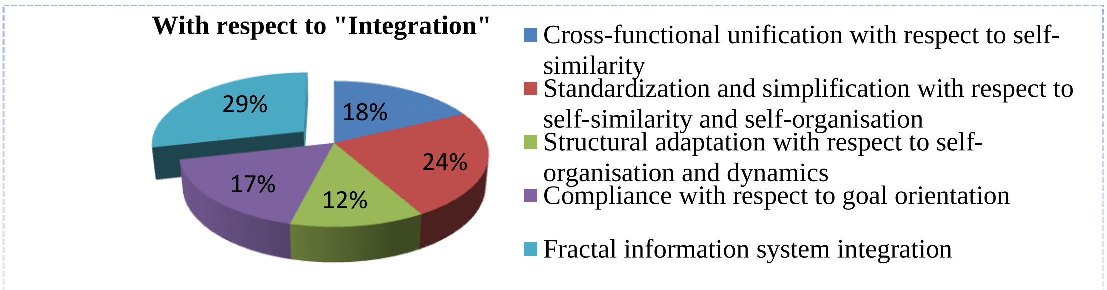


Lower sub-criteria prioritization with respect to the "Time management and logistics cost capability" and inconsistency measurement

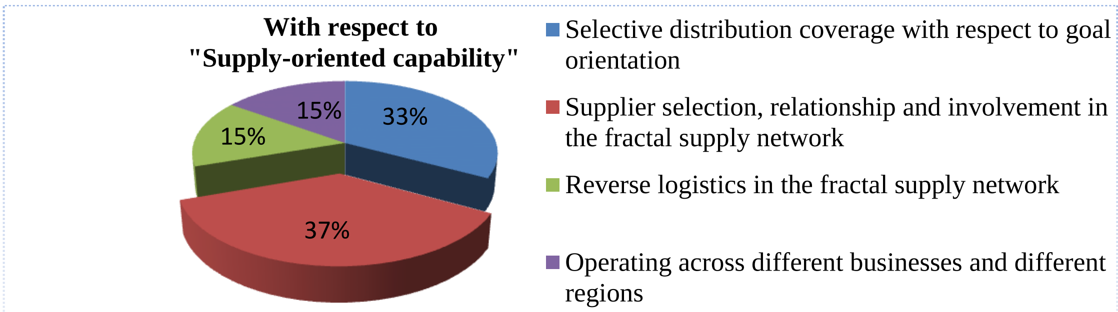
Appendix 2: Derivation of local priorities of the sub-criteria and lower sub-criteria (Fuzzy-AHP application)

Sub criteria weights with respect to the relevant main criteria

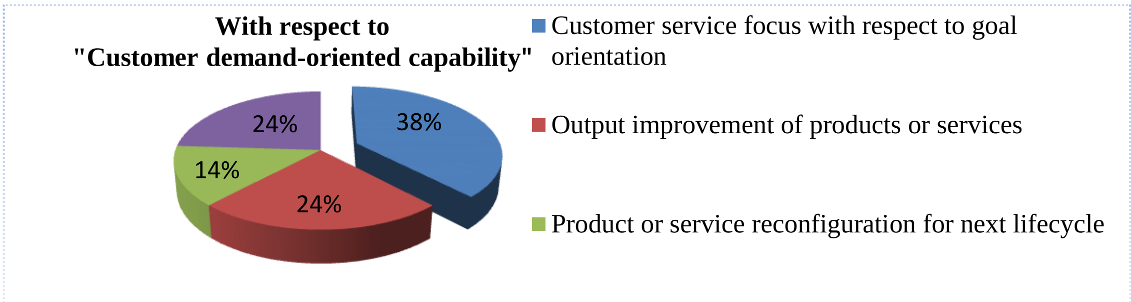
	Supplier	Supply hub	Manufacture	Distribution Centre	Retailer
Integration	0.282	0.261	0.141	0.084	0.216
Supply-oriented capability	0.180	0.306	0.044	0.156	0.269
Customer demand-oriented capability	0.240	0.210	0.219	0.156	0.281
Information exchange capability	0.181	0.048	0.188	0.302	0.074
Time management and logistics cost capability	0.117	0.175	0.408	0.302	0.160



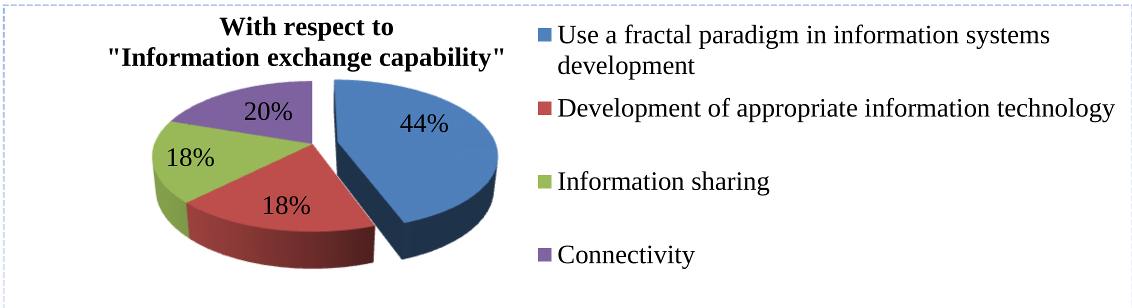
Lower sub-criteria prioritization with respect to the "Integration"



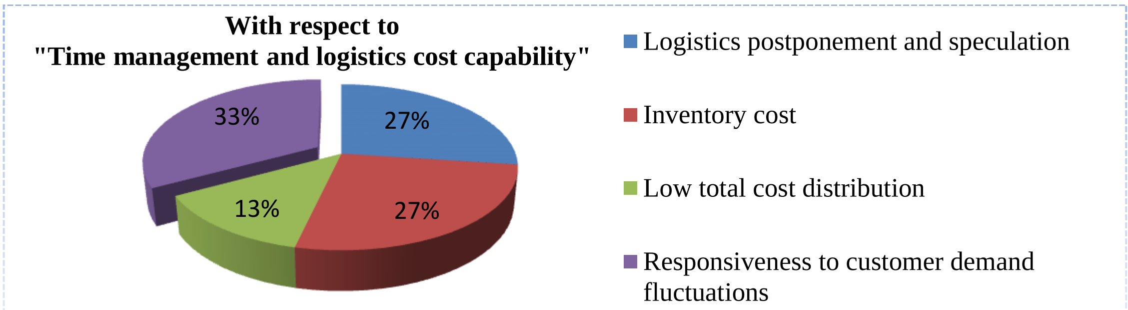
Lower sub-criteria prioritization with respect to the "Supply-oriented capability"



Lower sub-criteria prioritization with respect to the "Customer demand-oriented capability"

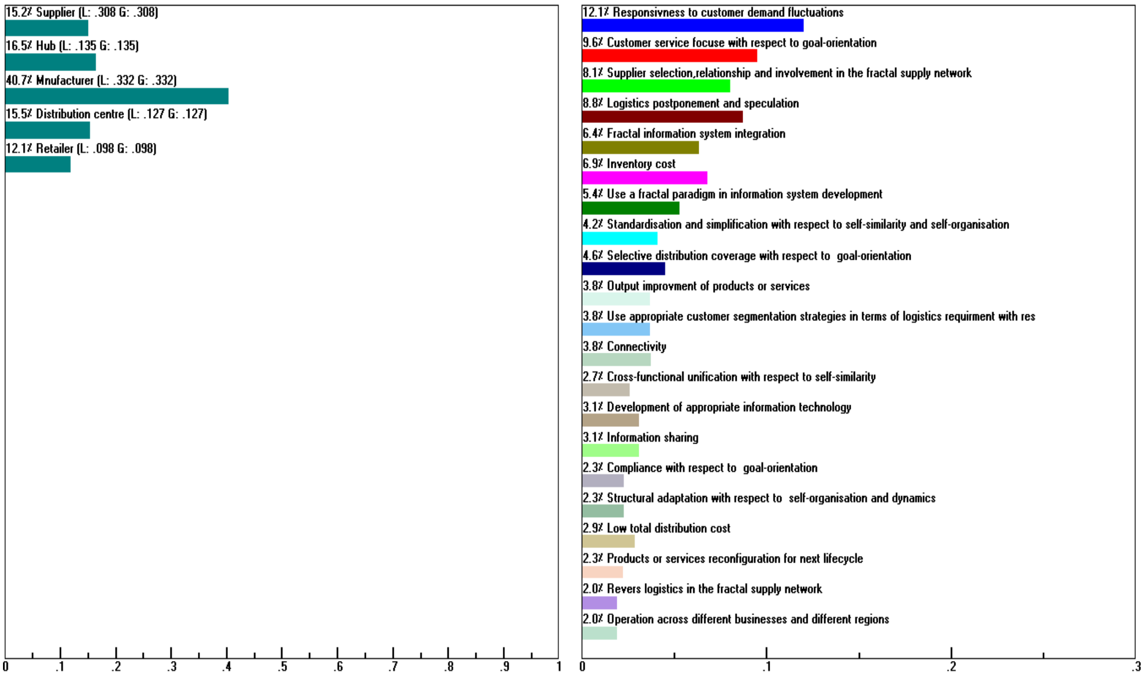


Lower sub-criteria prioritization with respect to the "Information exchange capability"

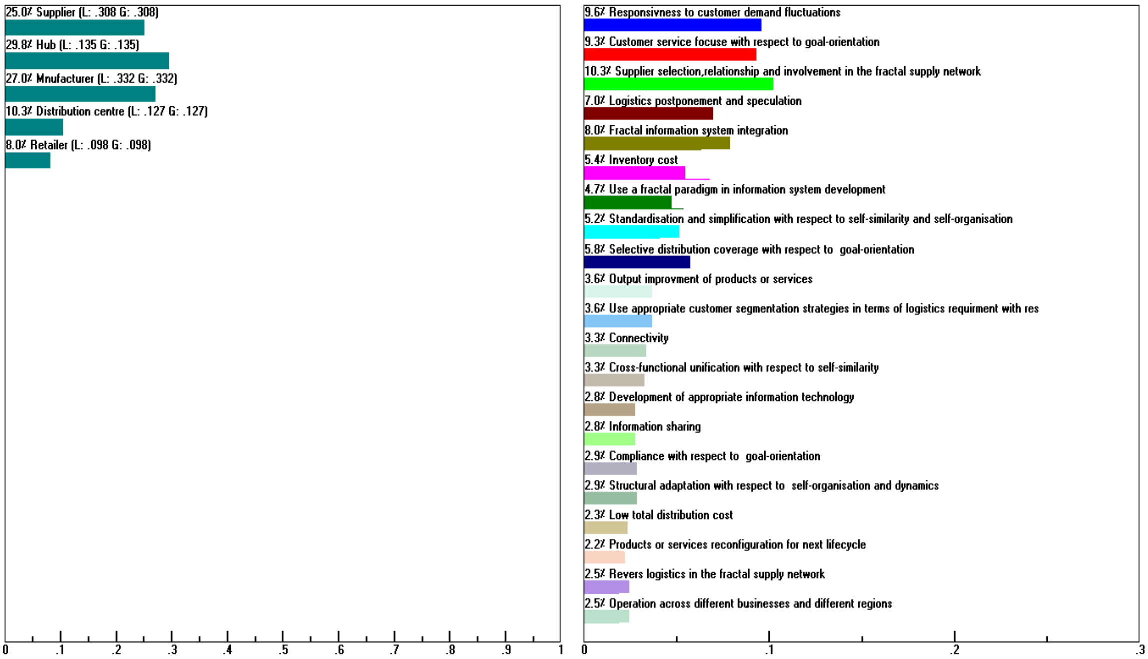


Lower sub-criteria prioritization with respect to the "Time management and logistics cost capability"

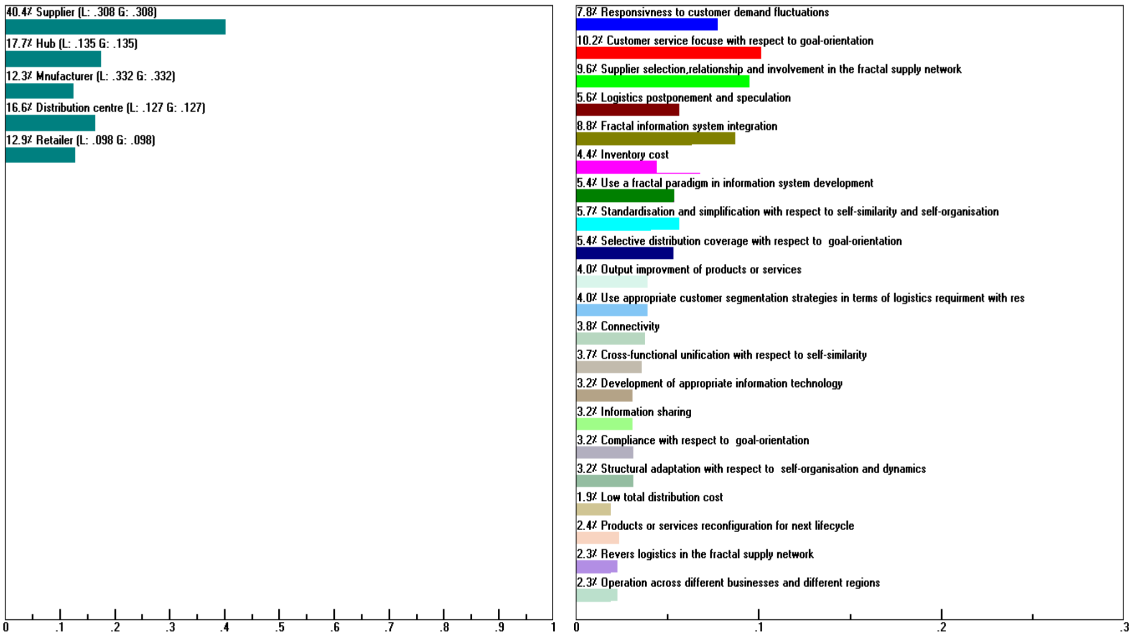
Appendix 3: Sensitivity analysis



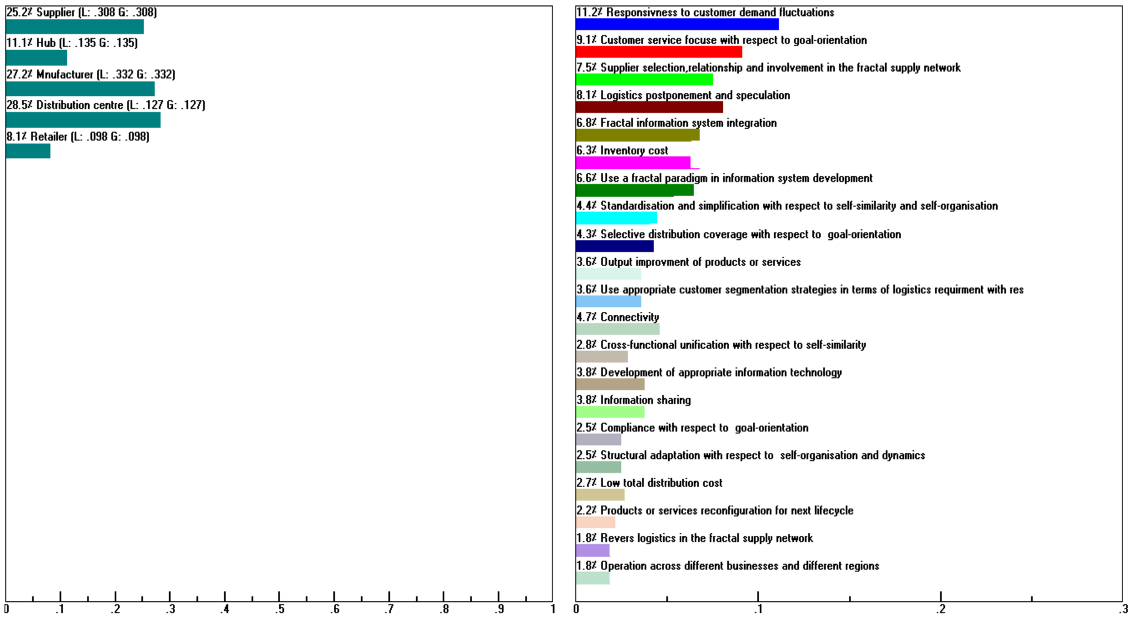
First scenario of Sensitivity analysis



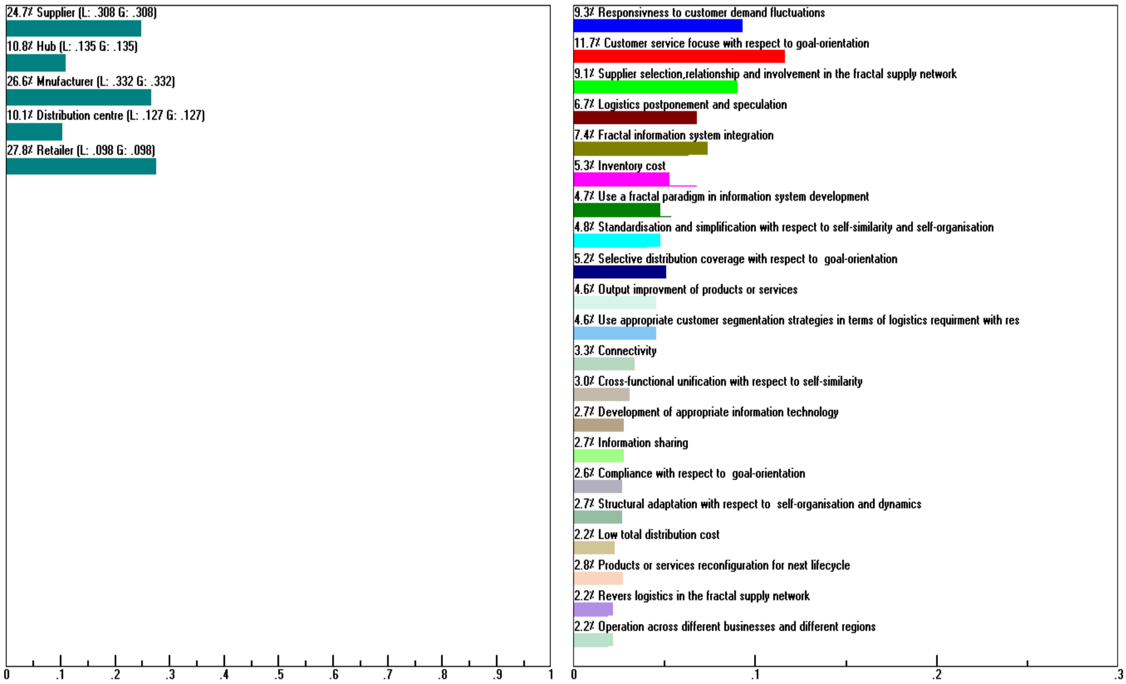
Second scenario of Sensitivity analysis



Third scenario of Sensitivity analysis



Fourth scenario of Sensitivity analysis



Fifth scenario of Sensitivity analysis